ANOPP2 Training Part 2 of 4: Aircraft System Noise Prediction

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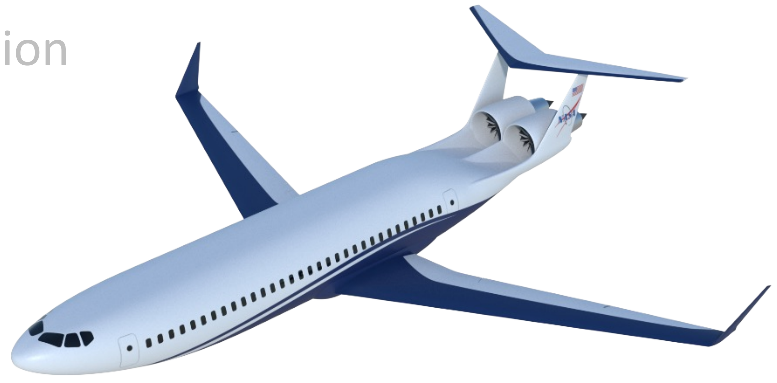
Outline of Introduction Videos

1. Brief introduction into aircraft system noise prediction
   - Fixed wing aircraft noise sources, installation effects, and prediction
   - Rotorcraft noise sources, installation effects, and prediction
   - Advanced air mobility noise sources, installation effects, and prediction
2. **Aircraft system noise prediction overview**
   - **Component source noise prediction**
   - **Atmospheric propagation and ground effects**
   - **Acoustic metric evaluation and aircraft acoustic certification**
   - **Auralization and community noise**
   - **Aircraft design optimization including noise**
3. Introduction into ANOPP2
4. Installation and Execution

This Video

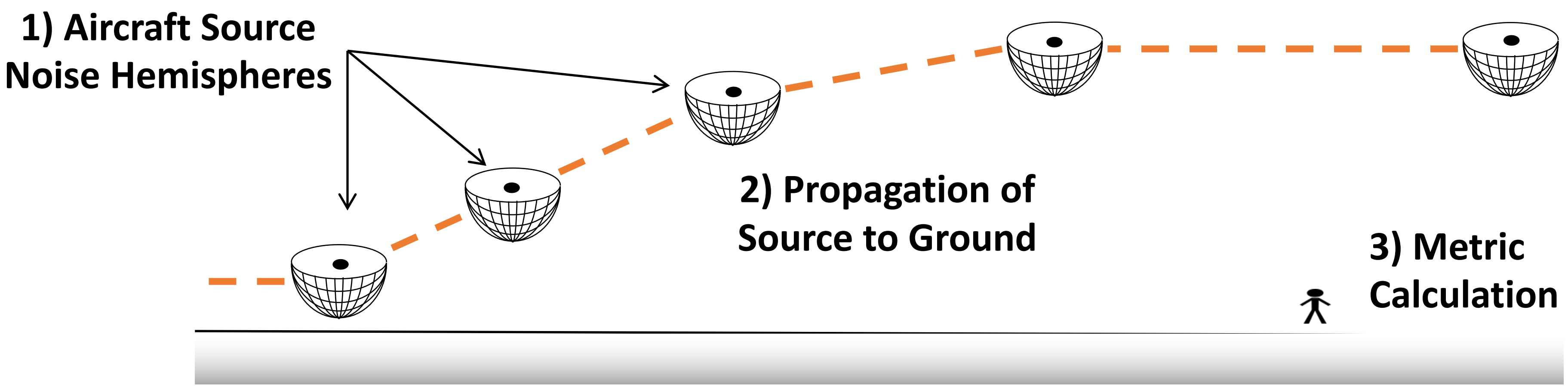


➢ **Target audience**
- **Some knowledge of acoustics and vehicle noise**
- **Some experience running acoustic and/or CFD software**

Image Credit: NASA concept vehicles

Development of Prediction Methods

- Development of prediction methods is critical for aircraft system noise prediction
  - Validation of all noise sources from vehicle in flight is very expensive
  - Requires adequately instrumented vehicle with qualified pilot over several days in an acoustically quiet outdoor environment with appropriate ground measurement equipment
- Noise source prediction methods are typically of one or a small number of noise sources
  - For instance: broadband self noise or engine core noise
  - Much easier to validate noise prediction methods using wind tunnel experiments
- Aircraft system noise prediction includes many source noise methods with validation exercises and few full vehicle validation exercises



Component Source Noise Prediction

- For noise source analysis, comparing to wind tunnel measurements is essential
- Small set of flight conditions (test matrix), no continuous flight event
- Array of many microphones for single test to potential flyover radiation vectors
- Predict each source and sum to compare to measured noise
  - Includes interaction effects if vehicle body or multiple noise sources
- In some instances, sources can be identified from measured data
  - Noise component to noise component validation

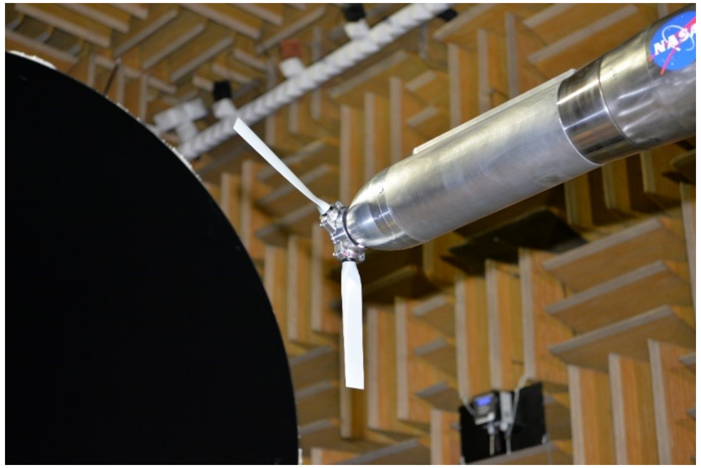
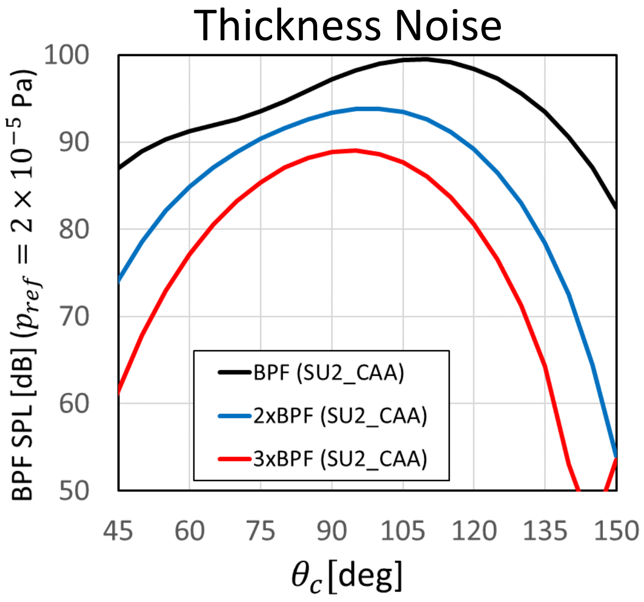
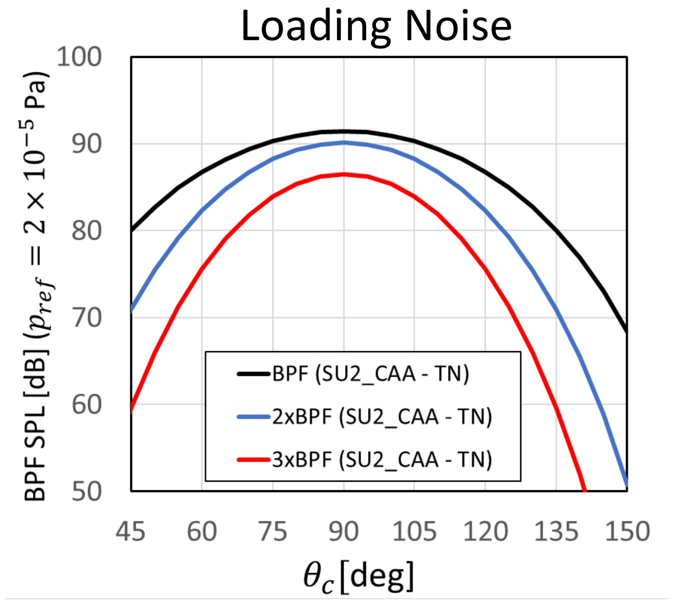


Image Credit: Nik Zawodny (NASA)





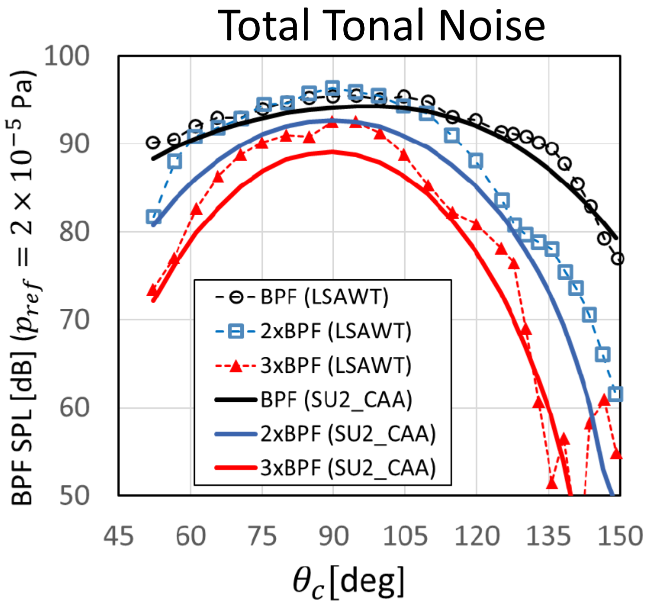
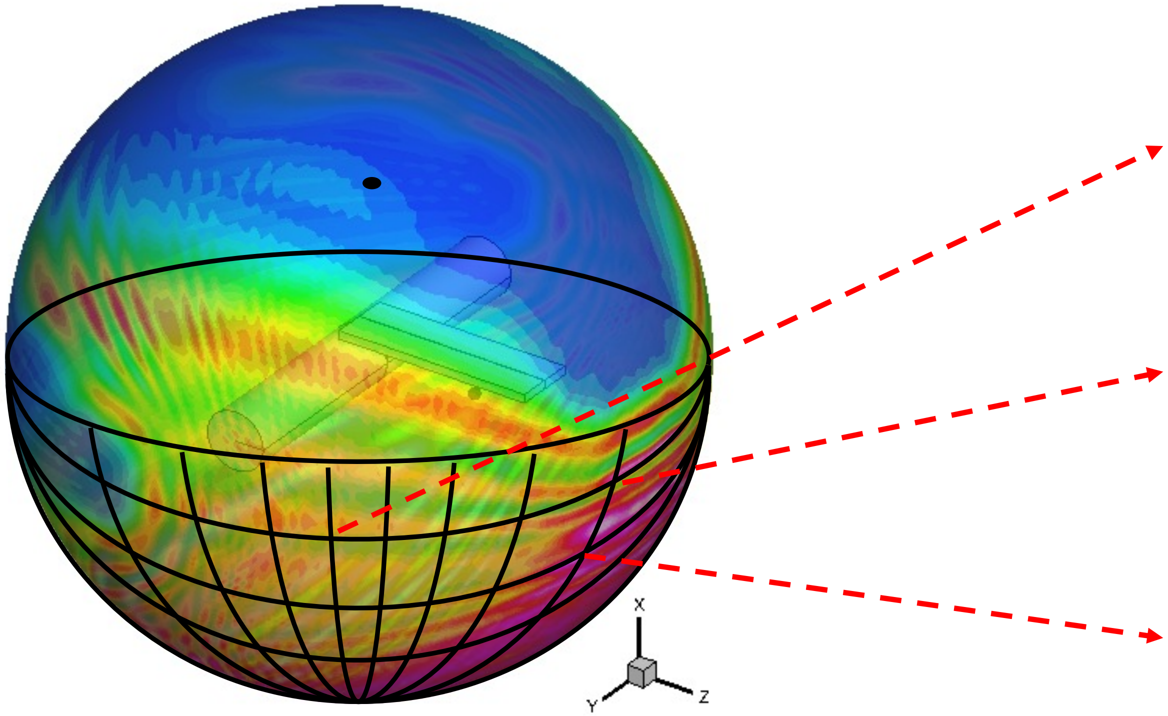
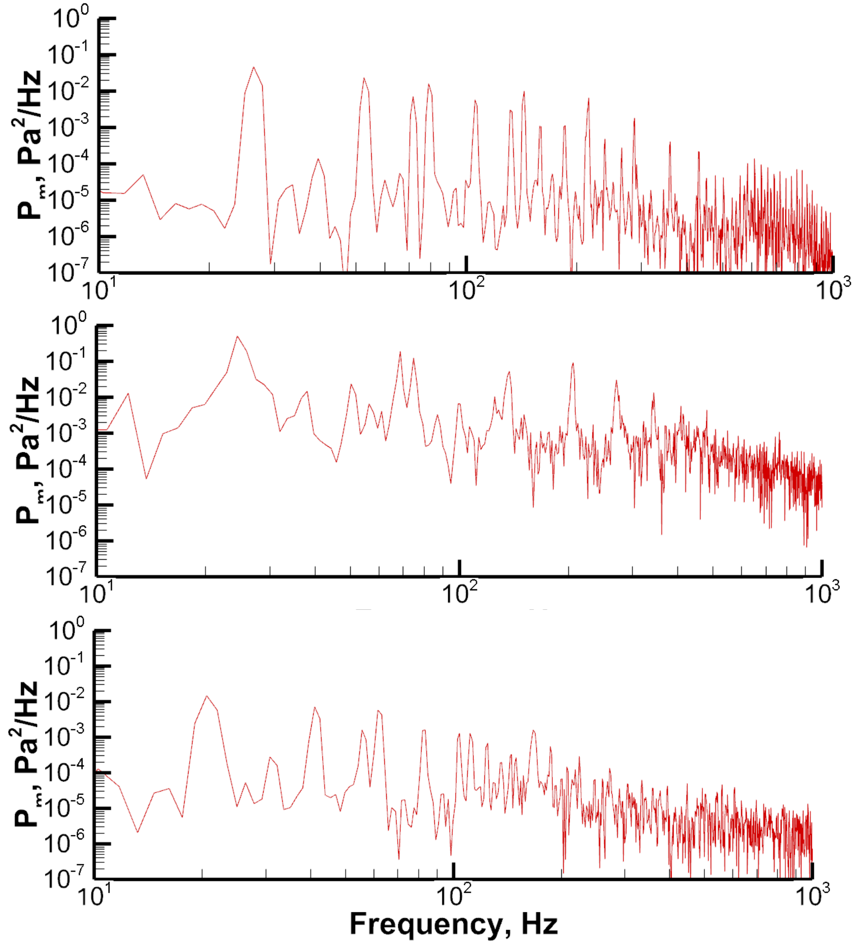


Image Credit: Omur Icke (ODU)

Component Source Noise Prediction

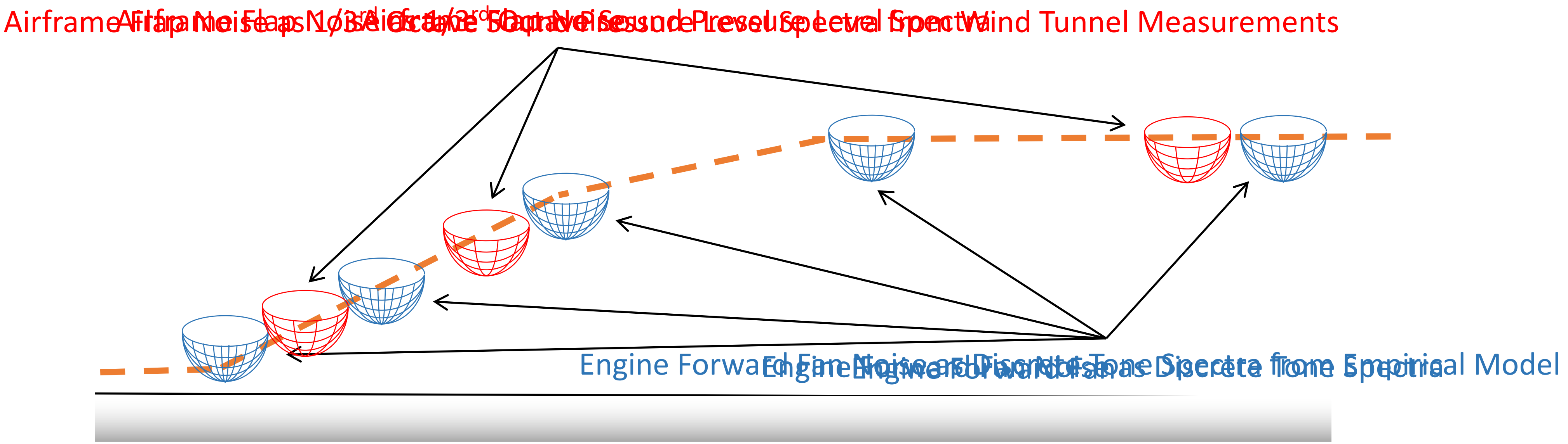
- Prediction method capable of predicting source noise metrics
  - Single noise source component (e.g., landing gear noise, broadband self noise)
  - Function of flight conditions (Mach number, atmospheric properties, etc.)
  - At many observer positions, usually a hemisphere





Component Source Noise Prediction

- Vehicle undergoing flight consists of many flight condition waypoints strung together
- Each noise source component can be predicted independently
  - Waypoints do not have to be consistent between noise sources (but usually are consistent)
  - Hemisphere resolution and/or acoustic metrics cast on hemisphere can be different
  - Noise source hemisphere can be from methods of different fidelity or from measurements
- Hemispheres can be added together if resolution and metric are consistent
  - Example: Sum all airframe sources into one source and all engine sources into a second source



ANOPP2

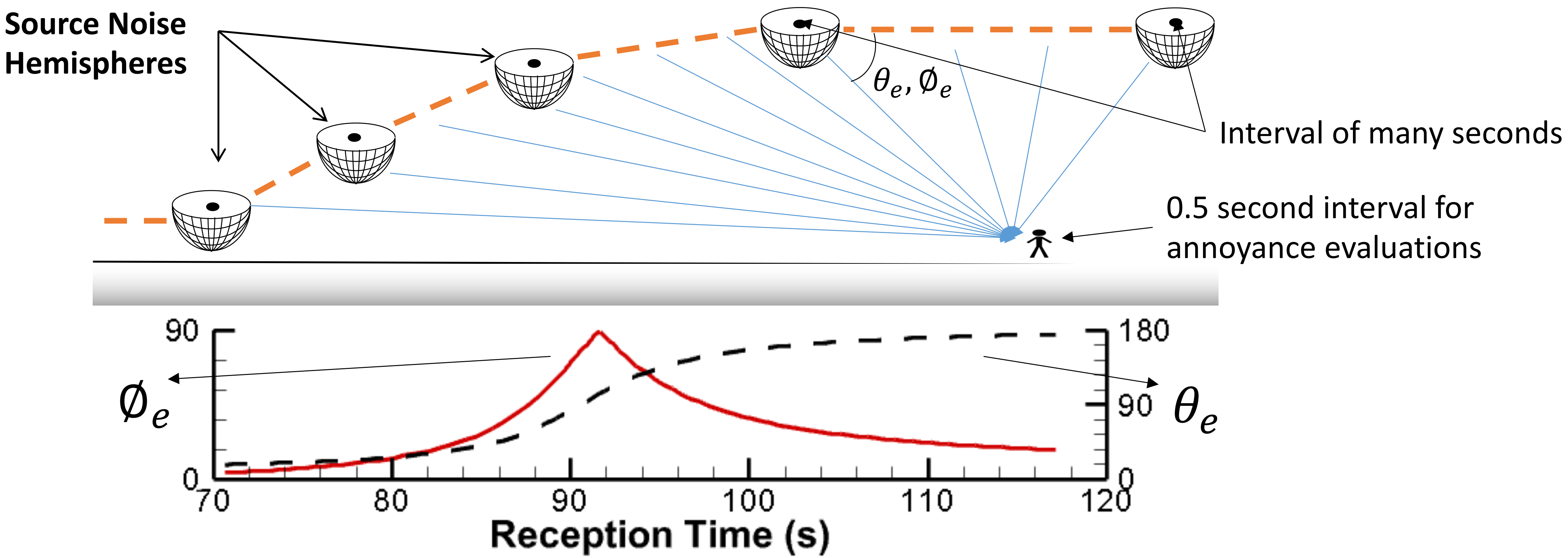
Atmospheric Propagation

τ: source time
t: reception time
$|r|$: radiation distance
$\bar{c}$: average speed of sound
θ_e: polar emission angle
$\emptyset_e$: azimuthal emission angle

- For metric evaluation, an observer-time-dominant approach is typically utilized
  - Source noise hemispheres are potentially many seconds apart and nonuniform in source time
  - For a set of reception times (typically at a 0.5 second resolution) a source time is calculated

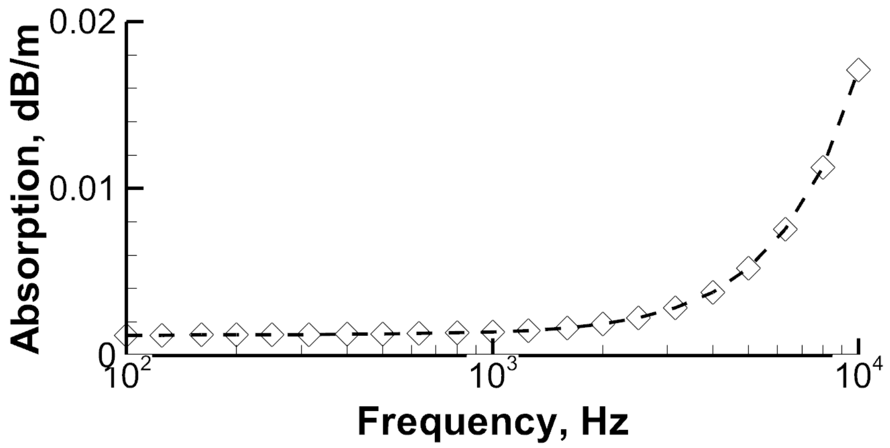
$$\tau = t - |r|/\bar{c}$$ ← Retarded Time Equation

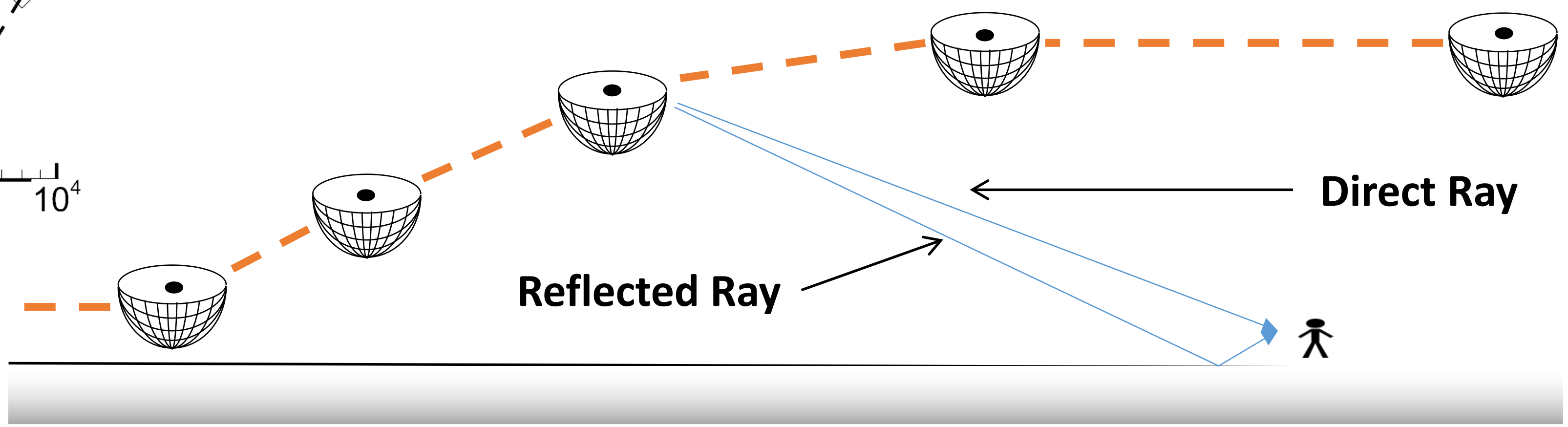
  - Source hemispheres are interpolated in space and time at emission angles and source time
  - Special care must be taken to account for tones and flight effects (Doppler and convective amplification)



Atmosphere and Ground Effects

- Additional suppression occurs for propagation, absorption, and ground effects
  - Spherical spreading of wave as a function of $|r|^2$
  - Atmospheric absorption applied in the frequency domain as a function of average atmospheric conditions
  - Higher frequencies are suppressed by the atmosphere more than lower frequencies
  - Ground attenuates the sound causing interference patterns with direct ray
  - Interference caused by difference in path length and ground impedance
  - Ground impedance impacted by ground type, example: grass versus concrete



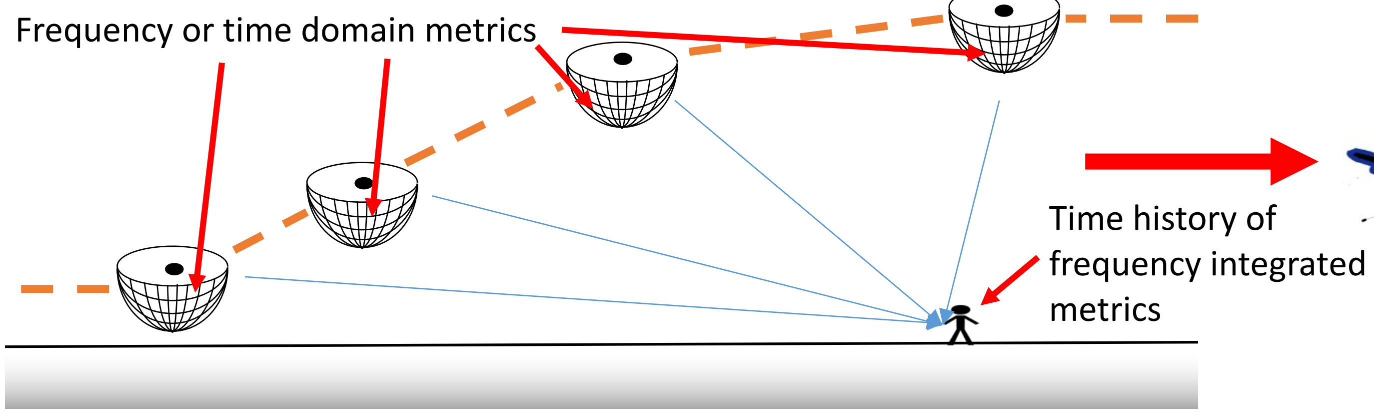


Aircraft Noise Certification

- Aircraft must pass government noise limits before being certified to fly
  - Similar hurdles exist for fixed wing aircraft and rotorcraft (AAM still being defined)
- Aircraft noise assessments include different source noise predictions
  - Potentially differing acoustic metric resolution at source and ground
  - Noise predictions at source and ground are used to calculated reduced order metrics
- More than one flight event is used to assess noise certification

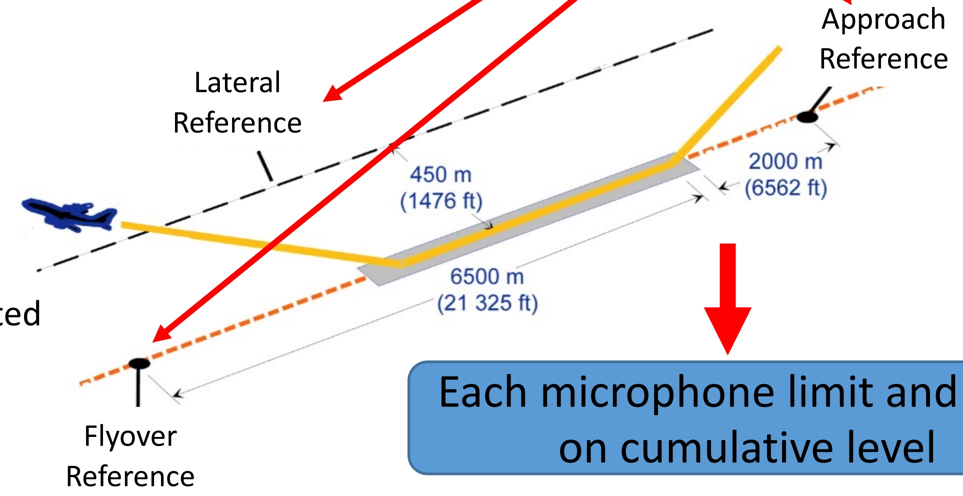
➢ Many different types of noise metrics may be used to assess vehicle noise

Source noise prediction and propagation



Frequency and time integrated metric

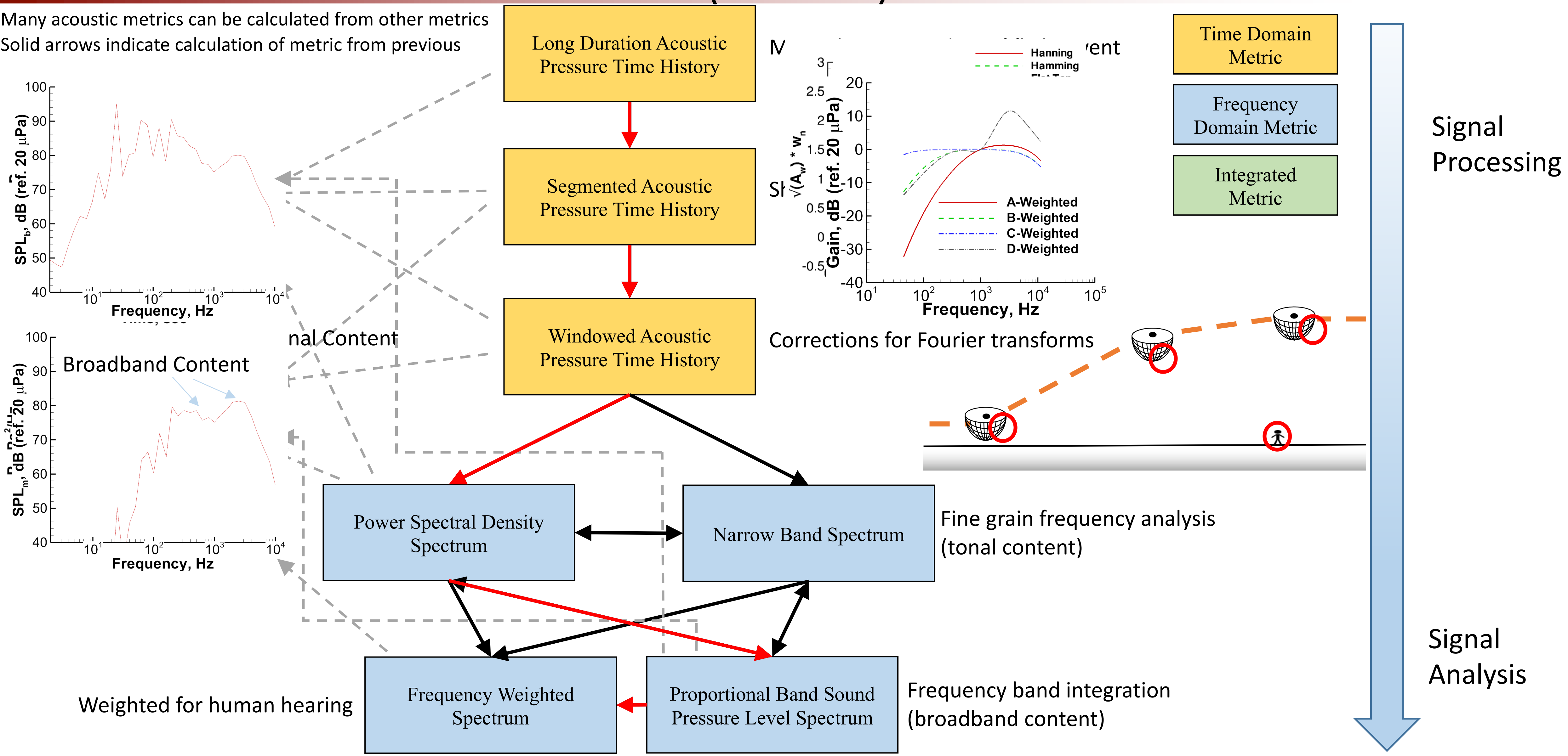
Aircraft noise assessment at certification microphones



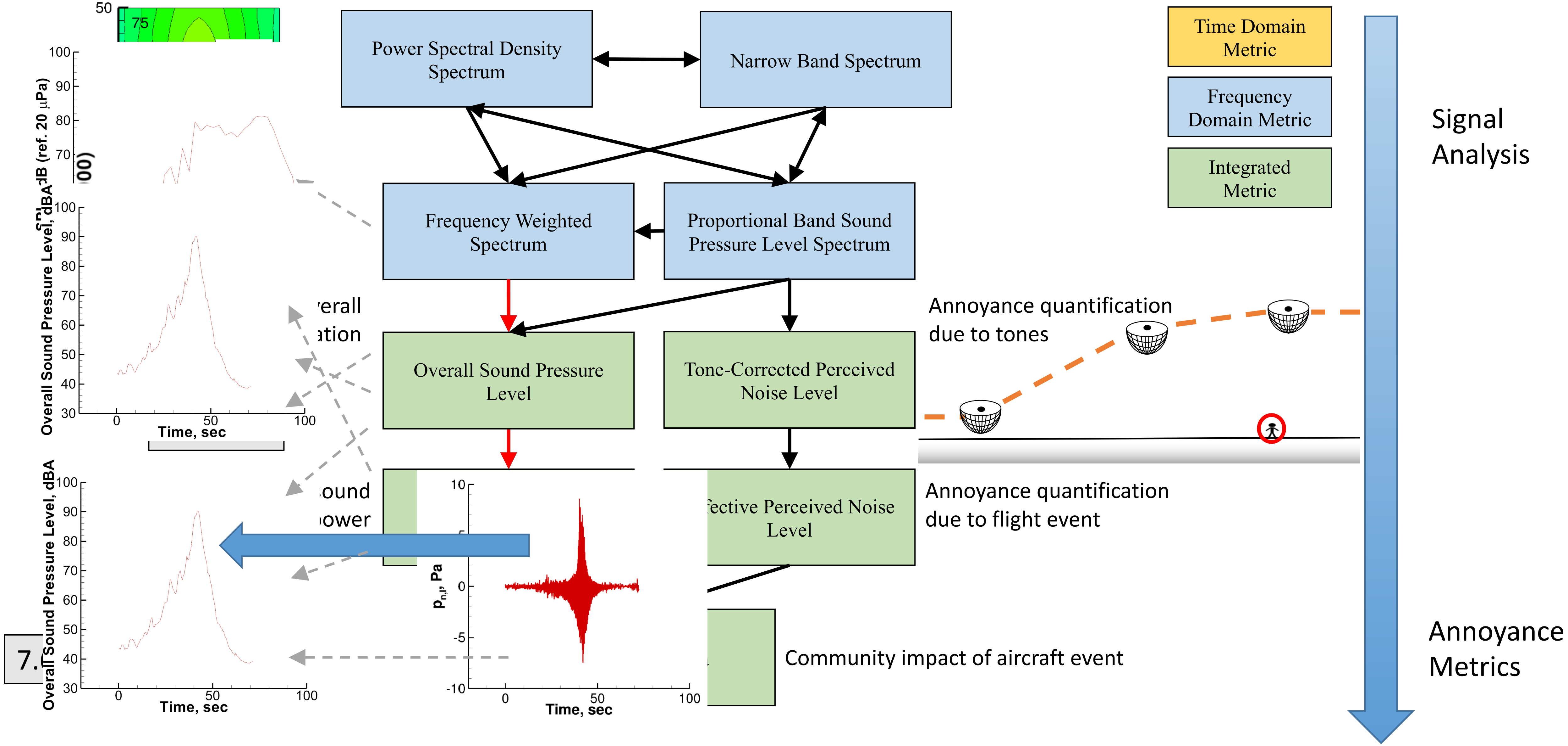
Each microphone limit and limit on cumulative level

Acoustic Metrics (1 of 2)

- Many acoustic metrics can be calculated from other metrics
- Solid arrows indicate calculation of metric from previous

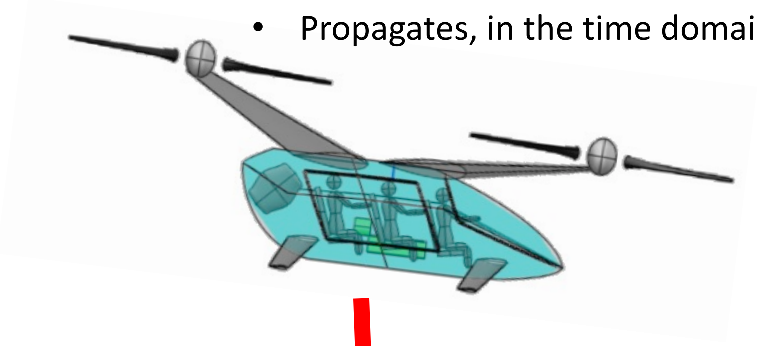


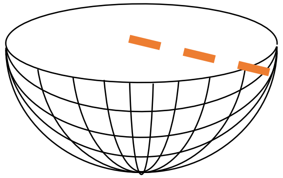
Acoustic Metrics (2 of 2)

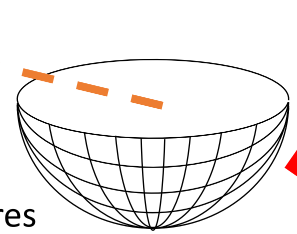


Auralization

- Acoustic metrics are good for noise analysis but impacts to communities usually involve multiple events
- Reduced order metric may be same value but derived from different higher order metrics
- Auralization is creating audible signal from predicted acoustic metrics or wind tunnel measurements
  - Audible signal can be listened to and assessed for annoyance
  - New annoyance metrics are being developed to better capture human response
- NASA's Auralization Framework (NAF)
  - Calculates audible signals at observer from hemisphere data
  - Propagates, in the time domain, to observer

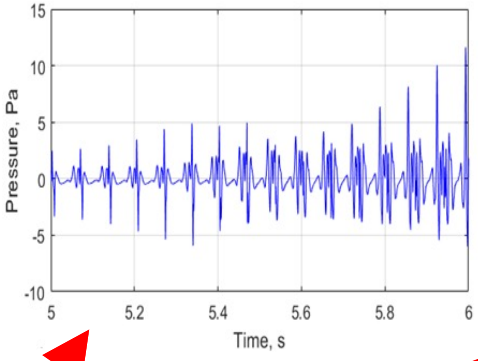




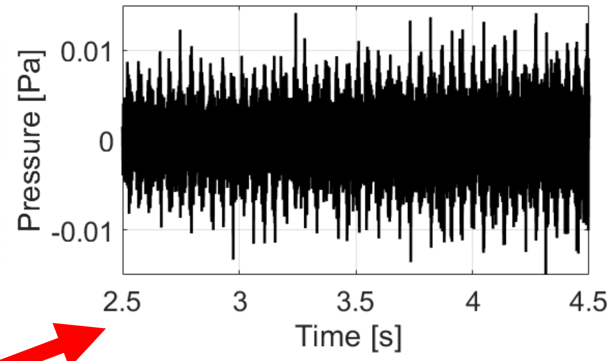


Noise prediction or
measurement hemispheres

Tonal Noise Auralization



Broadband Noise Auralization



Exterior Effects Room (EER)

New Acoustic Metrics

This is all well and good for a single observer
What about community annoyance?

Image Credit: Siddhartha Krishnamurthy and Stephen Rizzi (NASA)

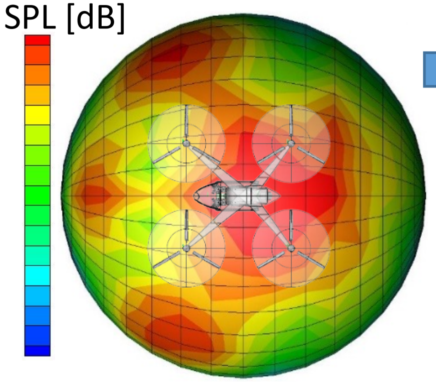
Community Noise Impact

- Single event noise prediction is ideal for acoustic study but not sufficient for community noise impact
  - Community impact of nearby airport requires many vehicle flight events of many different vehicles
- Single vehicle noise predictions feed into community noise impact assessment
  - Source noise hemispheres of various vehicles under various flight conditions are fed into design tool
  - FAA’s Aviation Environmental Design Tool (AEDT) simulates many flight paths to assess impact over large area
- Noise from entire airports is simulated and community impact assessed

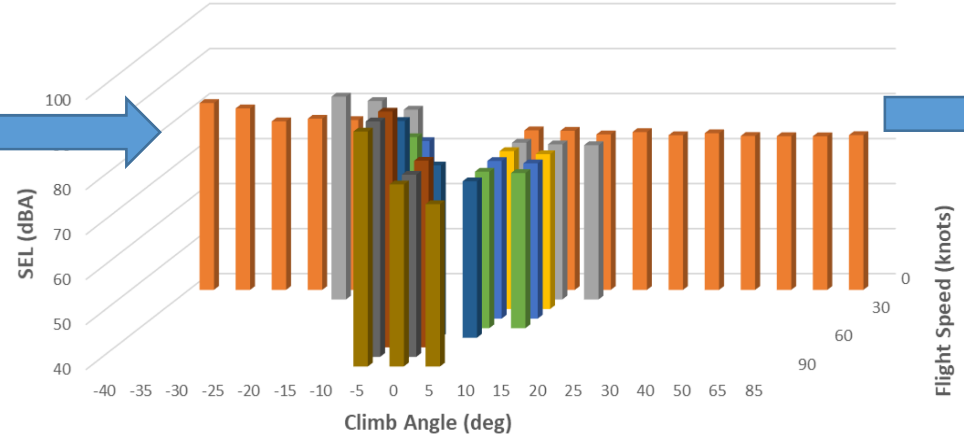
This is all well and good for our current vehicles
What should we do to reduce their noise?

Source Noise Prediction

SPL [dB]



Integrated Acoustic Metric Data



Community Impact

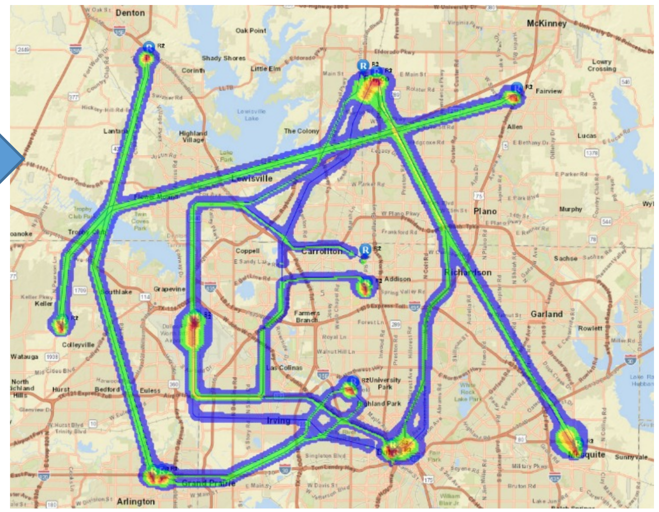


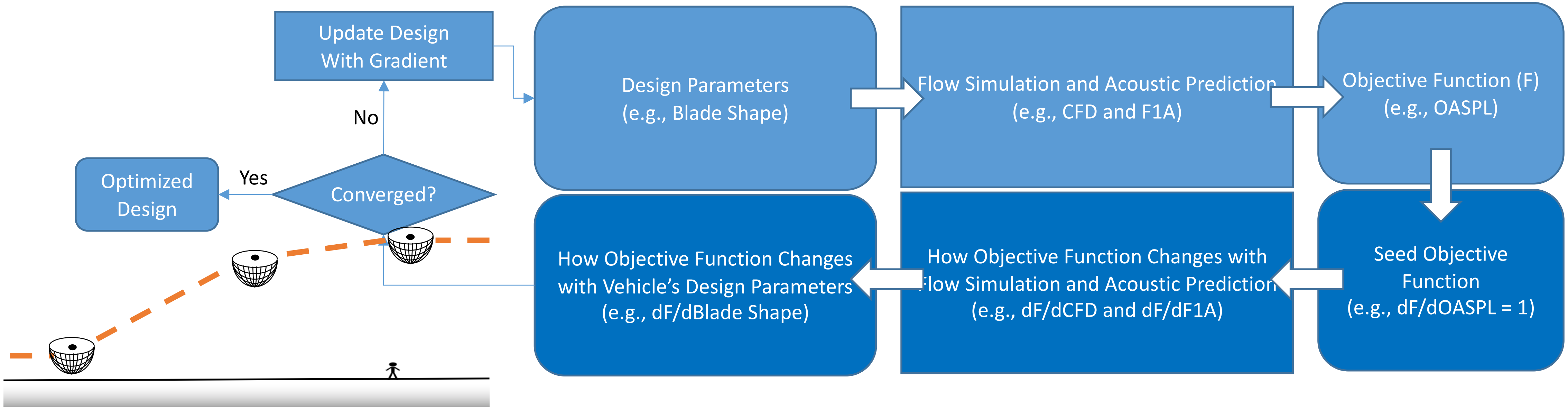
Image Credit: Stephen Rizzi (NASA)

Vehicle Design For Reduced Noise Impact

- Aircraft noise prediction involves many input properties (design parameters)
  - Aircraft geometric values, flight path and mission properties, atmospheric properties
- Quantification of noise involves typically few properties (objective function)
  - Total acoustic power level or number of people annoyed

➢ With given constraints, what set of design properties results in minimal noise?

- Design optimization procedure:



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